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## MOISTURE CONTENT OF WOOD IN DWELLINGS

By EDWARD C. PECK,<sup>1</sup> *Associate Wood Technologist, Forest Products Laboratory,*  
*Branch of Research, Forest Service*

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## INTRODUCTION

Wood, like many other fibrous materials, shrinks as it dries and swells as it absorbs moisture. Wood exposed to the air loses or absorbs moisture in accordance with its moisture content and the relative humidity of the surrounding air. The resulting changes in the moisture content of the wood cause it to shrink or swell, and these dimension changes when not kept within moderate limits cause many of the difficulties encountered in the use of wood in buildings.

The installation of wood at the proper dryness means practically no serious shrinkage later. It is a pleasure to own a house where the trim does not shrink noticeably, glued and mitered joints keep firmly in place, floors remain tightly laid, doors always fit snug, and the walls and ceilings are free from plaster cracks. Where such satisfaction is not obtained in a frame dwelling it is usually because the moisture in the wood changes after it is in place, at which time the only remedy in serious cases is extensive replacement and re-fitting.

On account of the great importance of limiting dimension changes in wood with changing atmospheric conditions, attempts have been made for many years to devise coatings or treatments that will "moisture proof" wood. No method or material has yet been dis-

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<sup>2</sup>Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

covered that will completely prevent moisture changes in wood, but it has been found practicable to reduce very materially, if not to eliminate entirely, troubles due to moisture changes. This may be accomplished by the use of wood that has been properly seasoned at the mill and then built into the structure at the moisture content corresponding to the average for the region in which the wooden product is to be used.

This publication furnishes definite recommendations based on a study by the Forest Products Laboratory of the moisture content of wood in service in dwelling houses in various regions throughout the United States. Although the moisture-content values given here are subject to revision as more complete information becomes available, nevertheless it is believed that in their present form they may serve as a guide for the lumber producer in seasoning his stock, for the dealer in handling it, and for the builder in using it. Most important to the owner, values are given that under ordinary conditions should prove satisfactory for establishing moisture specifications for wood delivered at the site of his new house and for the control of the moisture in the building during construction.

Frame dwellings have given good service for hundreds of years without their occupants knowing all the details of moisture content, so that the purpose of the information presented here is not for the first time to produce satisfaction, but to make a good house better through additional refinements made possible by modern methods.

#### RELATION OF MOISTURE CONTENT OF WOOD TO ATMOSPHERIC CONDITIONS

A succession of damp days in the summer is liable to cause doors to stick and bind, drawers to open with difficulty, windows to operate only under strong compulsion, and table tops to warp. On the other hand, during the winter, particularly when outdoor temperatures are very low and the fire is going full blast, the air within the house becomes extremely dry and in this condition is capable of absorbing moisture from every possible source in the room. Fruit standing on the dining-room table dries out quickly, and cut flowers wither in a very short time.

These two extreme conditions have marked effects upon any woodwork in the house. Under the moist conditions of the summer the woodwork swells; under the dry conditions of the winter the woodwork shrinks. This shrinking and swelling of wood clearly shows that the moisture content of wood in service is dependent mainly upon the relative humidity of the surrounding air. When wood is subjected to a constant relative humidity and temperature it will in time come to a definite moisture content, which is called the equilibrium moisture content. The relationship between the equilibrium moisture in wood, the temperature, and the relative humidity of the surrounding atmosphere is shown in Figure 1. From this figure it may be noted that the moisture content increases with increase in relative humidity but decreases with increase in temperature. Since outdoor temperatures are lower and relative humidities are higher in winter than in summer, the wood on the exterior of a house reaches a higher moisture content in the winter than in the summer. On the other hand, because of the low humidity prevailing

indoors in winter, the wood on the interior of a house usually reaches a lower moisture content in the winter than in the summer.

#### METHOD OF OBTAINING INFORMATION

The information presented here on the moisture content of the woodwork in dwelling houses was obtained in six cities widely scattered throughout the United States: Washington, D. C.; New Orleans, La.; Albuquerque, N. Mex.; San Francisco, Calif.;<sup>3</sup> Portland, Oreg.; and Madison, Wis. Each of these cities has a climate different from that of the others.

From six to eight houses in each of the foregoing cities were chosen, and small blocks of carefully dried wood were placed on various parts of each house in such a manner that the moisture con-

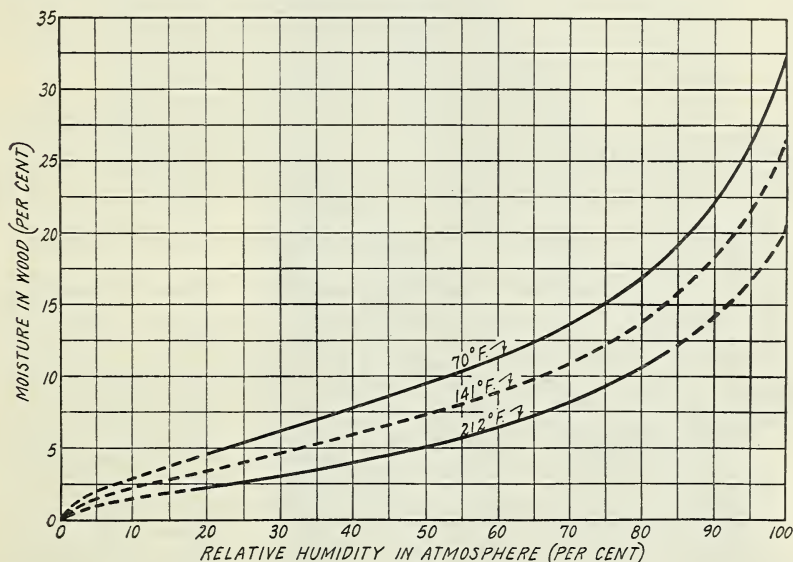


FIGURE 1.—The moisture content of wood increases with increase in relative humidity but decreases with increase in temperature

tent of the blocks would approximate that of the interior and exterior woodwork. The blocks were accurately weighed at intervals of one month throughout a period of 16 months, so that the moisture content and changes in moisture content of each block could be followed.

The blocks were separated into three groups, as follows: Bare, shellacked, and painted. The bare blocks were uncoated on the two faces and two edges, but were treated with two coats of shellac on each end. The shellacked blocks were shellacked with two coats on one face, two edges, and two ends, leaving one face bare. The painted blocks were painted on all surfaces, the two ends having also been previously covered with two coats of shellac. The bare and the shellacked blocks were used inside the dwellings, and the painted

<sup>3</sup> Houses listed under San Francisco were located in Berkeley, Oakland, Piedmont, and Burlingame.

blocks were used outside. (Pl. 1 and fig. 2.) The bare blocks served to give a quick response to changes in conditions while the shellacked blocks simulated the changes in moisture content in ordinary interior woodwork. The painted blocks were devised to correspond as nearly as possible to the painted exterior woodwork.

In all the houses blocks were installed in the living room, kitchen, bedroom, and bathroom which collectively are referred to here as the "living" part of the house. Blocks were also installed in the vestibule, attic, and basement of all the houses that had such

parts. In some instances where basements were lacking blocks were installed underneath the first floor several feet from the surface of the ground.

#### MOISTURE CONTENT OF INTERIOR AND EXTERIOR WOOD- WORK IN SIX WIDELY SEPA- RATED CITIES

The information obtained from the blocks is presented in various charts on which the moisture-content values obtained by weighting the blocks are plotted against the elapsed time the blocks had been installed on the various parts of the houses. Where possible, reference is made in the text to the moisture content of the interior or

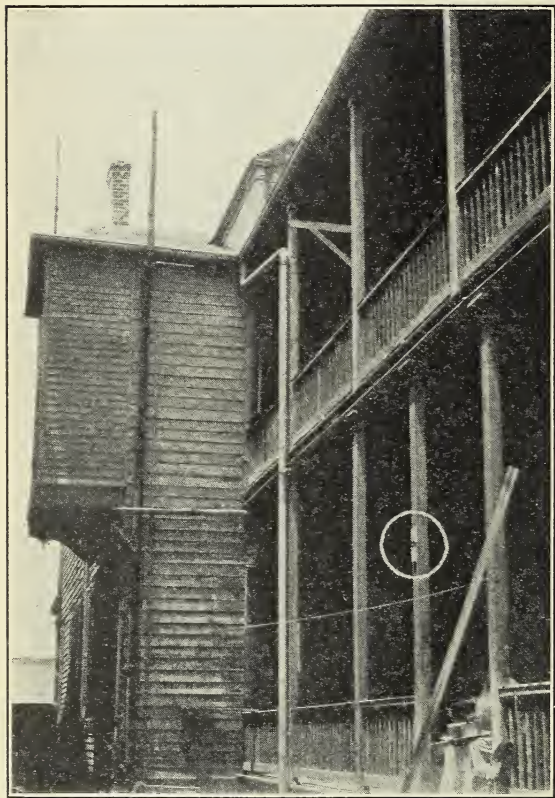
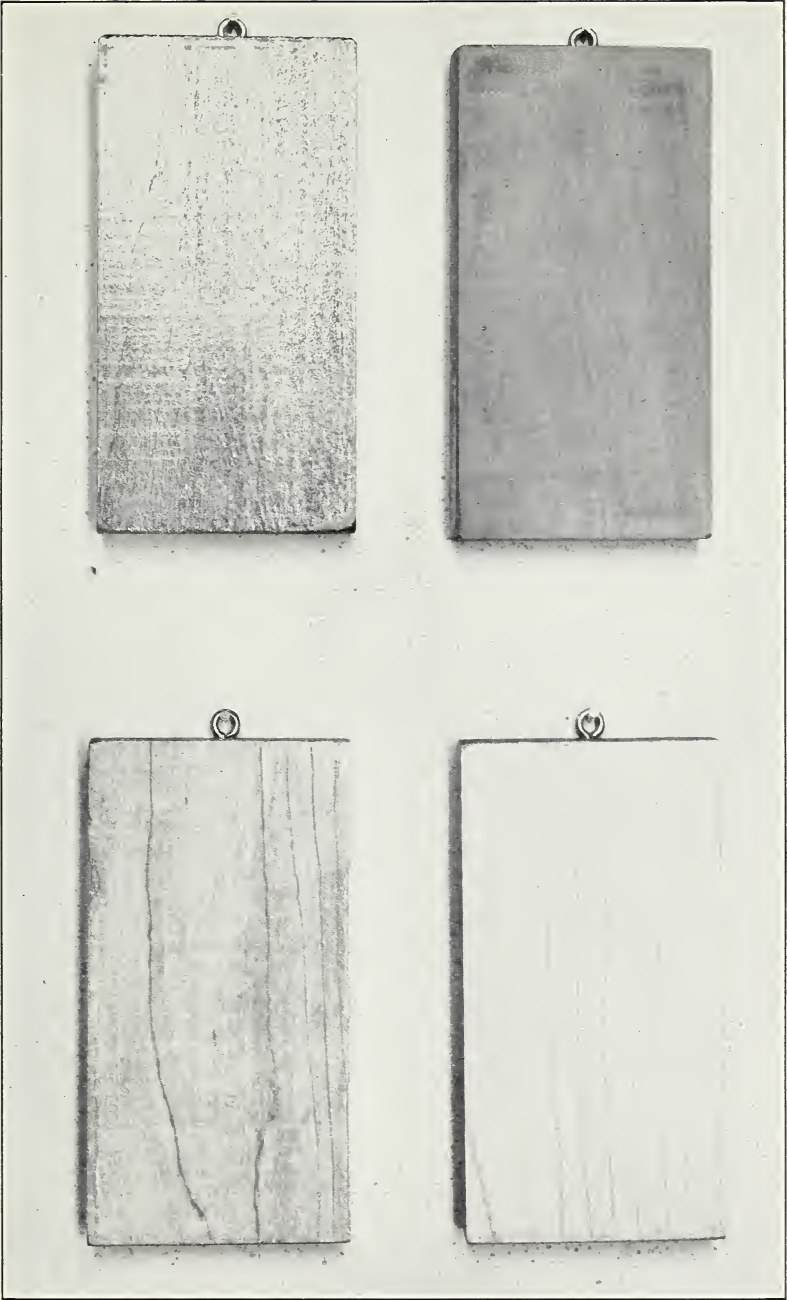


FIGURE 2.—Typical installation of blocks on a porch post outside a house

exterior woodwork rather than to that of the various blocks, since the weighings when analyzed indicated that the blocks were representative of the moisture content of the woodwork as a whole to which they were attached.

Figure 3 represents the average moisture content values of the interior woodwork in the "living" portion of the houses studied in each city. The curves are averages of the moisture-content values of 48 or more blocks and do not represent the moisture content values of the driest or the dampest house, nor do they show the wettest or driest block.



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Typical installation of blocks on an interior wall. The set consists of one bare and one shellacked block for each of two species



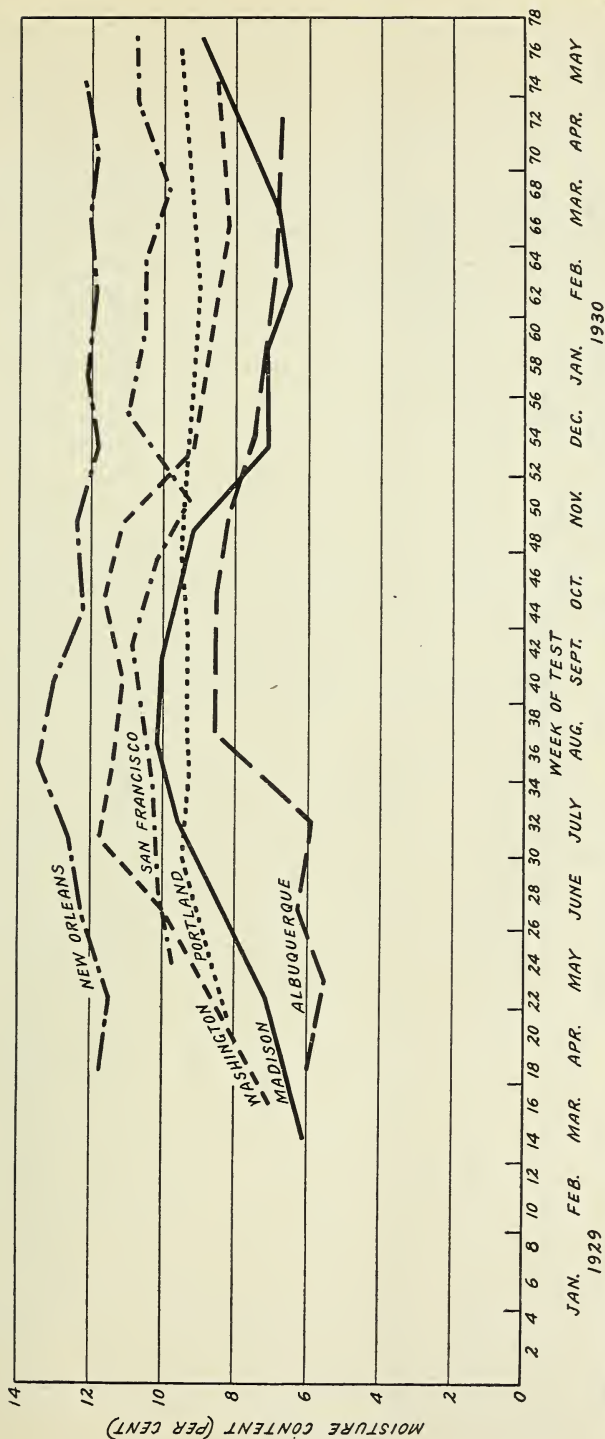


FIGURE 3.—The average moisture content for the principal interior woodwork in houses throughout the United States is about 9 per cent, except in arid regions and in warm, damp, coastal areas, according to this graph, which is based on the average moisture content of shellacked maple blocks in the "living" part of houses studied in six widely separated cities

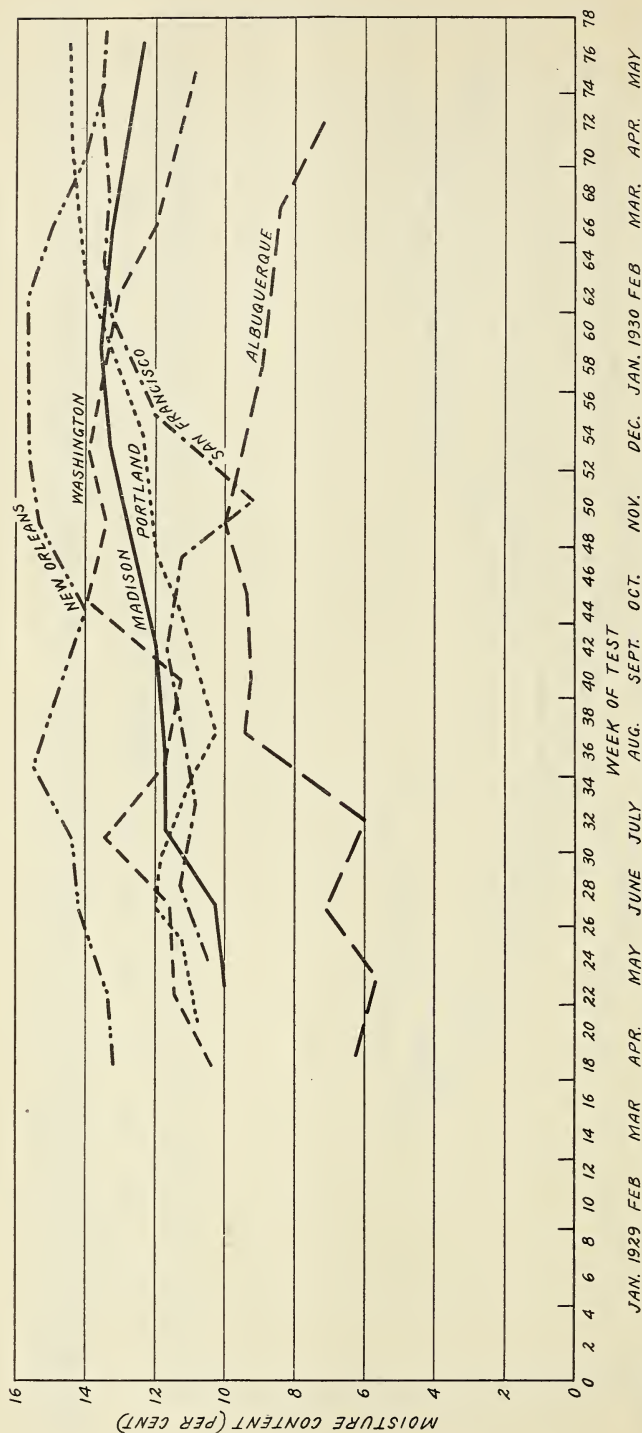


FIGURE 4.—The average moisture content for the principal exterior woodwork in houses throughout the United States is about 12 per cent, except in arid regions, where it is about 9 per cent according to this graph which is based on the average moisture content of painted maple blocks placed on the exterior of houses studied in six widely separated cities

The moisture content of the interior woodwork in the houses at New Orleans was consistently high throughout the year, while that of the houses at Albuquerque was, in general, low. The moisture content of the interior woodwork in the houses at Washington and Madison was low in the winter and higher in the summer. The moisture content values in the houses at San Francisco and Portland exhibited no marked seasonal changes.

Figure 4 represents the average moisture-content values of the exterior woodwork of the houses studied in each city. The greatest range in moisture content of exterior woodwork in any one city was about 4.5 per cent. This small seasonal range in moisture content was no doubt due largely to the fact that the blocks on the exterior of the houses were painted on all surfaces and their moisture content could not change rapidly enough through the paint to keep in equilibrium with the constantly changing atmospheric humidity. House siding and exterior trim under normal conditions should behave similarly, for although they are usually painted on one side only the other side is not freely exposed to the air.

The moisture-content values in Figures 3 and 4 show that the term "dryness," when referring to wood, is a relative matter. Thoroughly seasoned wood in New Orleans, La., may have a moisture content that would be considered too high for use in Albuquerque, N. Mex. In addition, one man's house differs from his neighbors' in dryness, according to the type of heating plant and the way it is run. (Table 1 and fig. 5.) Even different parts of the same house maintain their individual moisture atmosphere. (Fig. 6.)

TABLE 1.—Description of the houses in which the blocks were installed

| City          | Kind of house | Type of construction                                         | Type of roof covering   | Insulated | Type of heating plant       | Humidified | Exposure to sun | Exposure to wind |
|---------------|---------------|--------------------------------------------------------------|-------------------------|-----------|-----------------------------|------------|-----------------|------------------|
| Washington    | 2-story       | Brick and tile, first story; frame and stucco, second story. | Wood shingles           | No        | Hot water                   | No         | Moderate        | Slight.          |
|               | do            | Frame, stucco, and shingles                                  | Composition shingles    | No        | do                          | No         | do              | Do.              |
|               | do            | Frame, siding shingles                                       | Tin                     | No        | Hot air                     | No         | do              | Moderate.        |
|               | 2½-story      | Frame, siding                                                | Composition shingles    | No        | Hot water                   | Yes        | Full            | Full.            |
|               | 2-story       | Masonry-brick                                                | Wood shingles           | No        | do                          | No         | Slight          | Slight.          |
| New Orleans   | do            | Frame, stucco.                                               | Composition shingles    | No        | do                          | Yes        | Full            | Moderate.        |
|               | do            | Frame, siding                                                | Slate                   | No        | do                          | No         | do              | Do.              |
|               | do            | Frame, stucco.                                               | Tile                    | No        | Steam                       | No         | do              | Full.            |
|               | do            | Frame, siding                                                | Composition shingles    | No        | Hot water                   | No         | do              | Moderate.        |
|               | 2½-story      | do                                                           | Slate                   | No        | Hot water                   | No         | do              | Slight.          |
| Albuquerque   | Bungalow      | do                                                           | do                      | No        | Fireplace, oil stoves       | No         | Moderate        | Do.              |
|               | 2-story       | do                                                           | do                      | No        | Fireplace, gas heaters.     | No         | Full            | Full.            |
|               | Bungalow      | Adobe                                                        | Composition, built up.  | No        | Hot air, pipeless           | Yes        | do              | Do.              |
|               | do            | Frame, stucco                                                | Wood shingles           | No        | do                          | Yes        | do              | Do.              |
|               | do            | Hollow tile, brick                                           | Composition, built up.  | No        | do                          | Yes        | do              | Do.              |
| San Francisco | do            | Frame, stucco                                                | Composition shingles    | No        | do                          | Yes        | do              | Do.              |
|               | do            | Adobe, stucco                                                | Prepared roofing strips | No        | do                          | Yes        | Moderate        | Moderate.        |
|               | do            | Frame, siding                                                | Wood shingles           | No        | do                          | Yes        | Full            | Full.            |
|               | 2-story       | Frame, stucco                                                | Composition, built up.  | No        | Stove                       | No         | do              | Do.              |
|               | do            | Frame, siding and shingles                                   | Composition shingles    | No        | Hot air                     | Yes        | do              | Slight.          |
| Portland      | Bungalow      | Frame, shingles                                              | Wood shingles           | No        | Stove                       | No         | Moderate        | Do.              |
|               | do            | Frame, stucco                                                | do                      | No        | Fireplace, gas floor heater | No         | Full            | Moderate.        |
|               | do            | Frame, siding                                                | do                      | No        | Floor heater                | No         | do              | Slight.          |
|               | 1½-story      | Frame, shingles                                              | Tile                    | No        | Fireplace, gas heater       | Yes        | do              | Full.            |
|               | do            | Frame, stucco                                                | Wood shingles           | No        | Hot air                     | No         | do              | Do.              |
| Madison       | do            | Frame, siding                                                | do                      | No        | do                          | No         | Moderate        | Moderate.        |
|               | 2-story       | Tile, stucco                                                 | do                      | Yes       | do                          | No         | do              | Do.              |
|               | do            | Frame, shingles                                              | do                      | No        | Hot water                   | No         | Slight          | Do.              |
|               | do            | Frame, stucco                                                | do                      | No        | Hot air                     | No         | Full            | Do.              |
|               | do            | do                                                           | do                      | No        | do                          | Yes        | do              | Full.            |
| Madison       | 1½-story      | Frame, siding and shingles                                   | do                      | No        | do                          | Yes        | Slight          | Slight.          |
|               | do            | Frame, stucco                                                | do                      | Yes       | Hot water                   | No         | Full            | Full.            |
|               | 2-story       | Frame, siding                                                | Composition shingles    | No        | Hot air                     | Yes        | Moderate        | Moderate.        |
|               | do            | do                                                           | Wood shingles           | No        | Stove                       | No         | Full            | Full.            |
|               | 1½-story      | Frame, shingles                                              | Composition shingles    | Yes       | Hot air                     | Yes        | do              | Moderate.        |
| Madison       | do            | Frame, brick and stucco                                      | do                      | No        | Hot water                   | No         | Moderate        | Do.              |
|               | 2-story       | Frame, stucco                                                | do                      | Yes       | do                          | No         | Full            | Full.            |
|               | do            | Frame, siding                                                | Wood shingles           | No        | Steam                       | No         | Slight          | Slight.          |
|               | do            | do                                                           | do                      | No        | do                          | No         | do              | Do.              |
|               | do            | do                                                           | do                      | No        | do                          | No         | do              | Do.              |

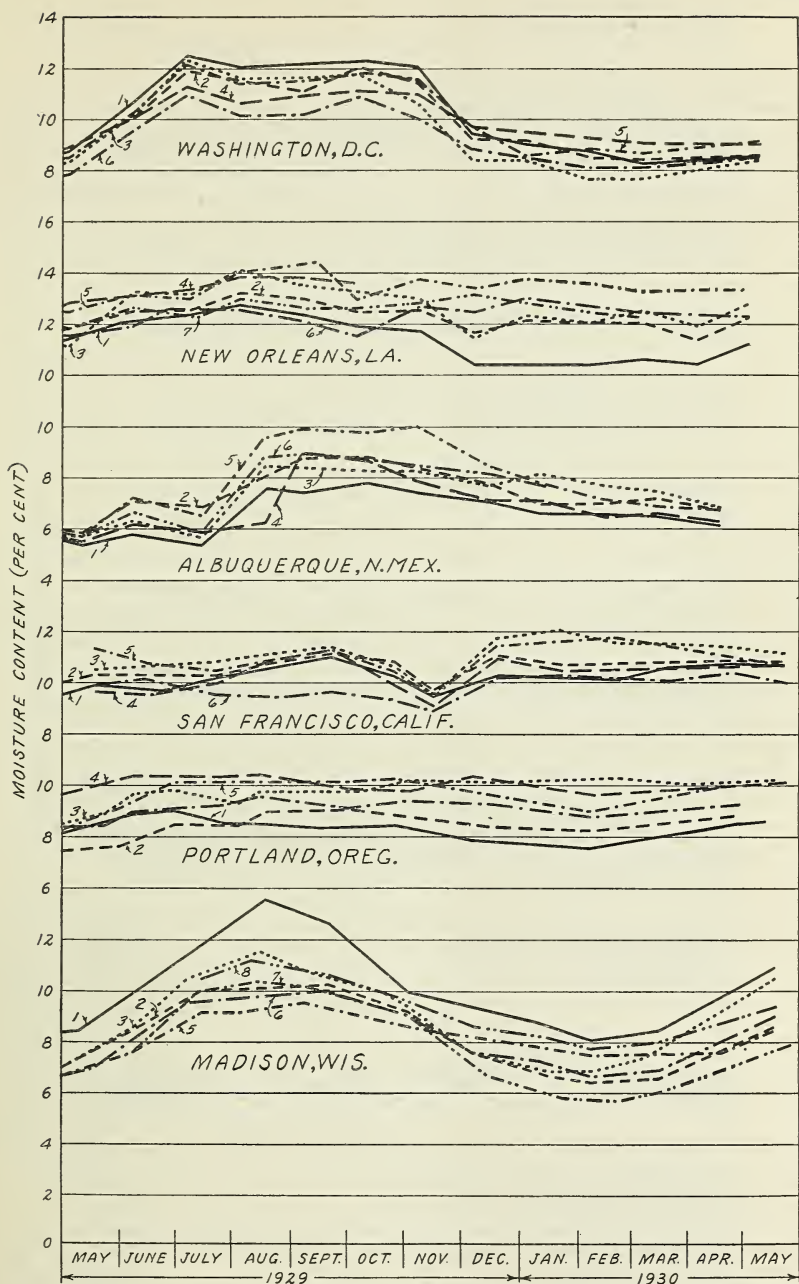


FIGURE 5.—The moisture content of the woodwork of individual houses in any one city is not uniform. This fact is indicated by the average moisture content of shellacked maple blocks in the "living" part of each house studied in six widely separated cities. The numbers on the curves refer to the individual houses

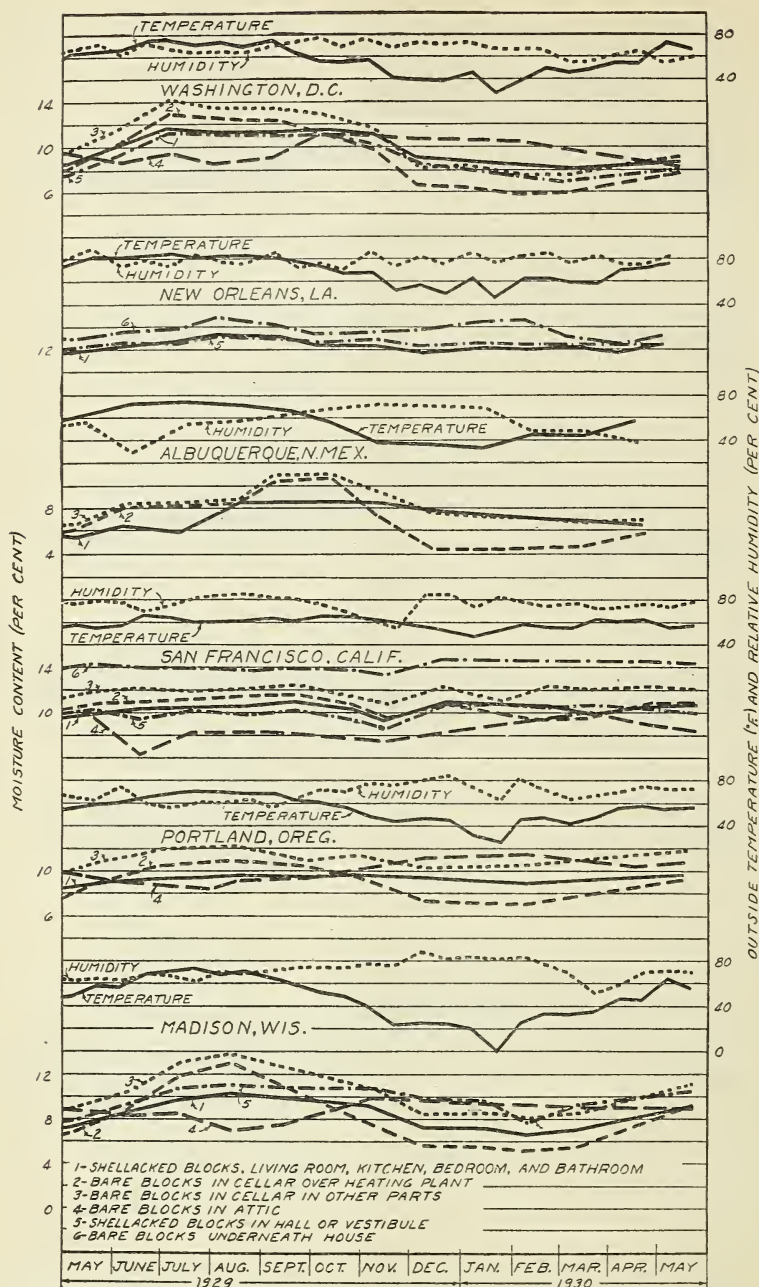


FIGURE 6.—The moisture content of the interior woodwork, with the exception of that in the attic, follows the outdoor temperature curve—up in summer and down in winter. This graph is based on the average moisture content of the shellacked maple blocks representing the interior woodwork in various parts of houses studied in six widely separated cities and on the corresponding outdoor temperature and relative humidity

## RELATION BETWEEN THE MOISTURE CONTENT OF INTERIOR WOODWORK AND CLIMATIC CONDITIONS THROUGHOUT THE UNITED STATES

During the winter the moisture content of interior woodwork is affected by the difference between the outdoor and indoor temperatures, but since houses are heated to about the same temperature in winter—namely, 70° F.—the outside temperature is really the controlling factor. If the air in houses could be maintained at the proper relative humidity throughout the winter, the severe drying and shrinking of the wood could be prevented, but such control is not within reach of many people at the present time. Furthermore, such humidification is complicated and the degree to which it can be accomplished is limited in cold weather by the condensation of moisture from the air in the house upon the cold surfaces of windows and the cold surfaces within the walls of the house. The condensation may in some cases cause more serious troubles than result from the dryness of the air. During the summer, when no heat is required and doors and windows are open, the higher the outdoor relative humidity, the higher the moisture content of the interior woodwork. Consequently, although the moisture content of woodwork was studied in six cities only, the average moisture content of interior woodwork in ordinary dwellings in any city of the United States may be predicted approximately by the use of weather maps that give the temperature during the winter and relative humidity during the summer.

Figure 7 shows a map of the United States on which are drawn average temperature lines for January. Lines of average moisture content of interior woodwork, located by means of the data for the foregoing six cities and made to conform with the shape of the temperature lines, are also drawn on the map. The calculated moisture content averages for January range from about 4 per cent, in northern Minnesota and North Dakota, to more than 12 per cent, in the Gulf States.

Figure 8 shows the average minimum relative humidity for July and also the average moisture content of interior woodwork. The average minimum relative humidity was used for the comparison of one region with another because it is readily available from current observations of the Weather Bureau. The driest portion of the country during this month is Nevada and adjacent territory, while the dampest parts are along the Atlantic, Gulf, and Pacific coasts. The Great Lakes region is a trifle less damp than the coastal regions. The calculated average moisture-content values for interior woodwork for July range from about 4 per cent in the driest parts of the United States to about 13 per cent along the coasts.

In the consideration of these maps it must be borne in mind that the values are based on average weather conditions; therefore, for any particular year the values may fall above or below those given. Also the values are based on information from all of the houses where the blocks were studied in each of the six cities; consequently an individual house anywhere in the country may contain woodwork the moisture content of which may be lower or higher than the value indicated on the map.

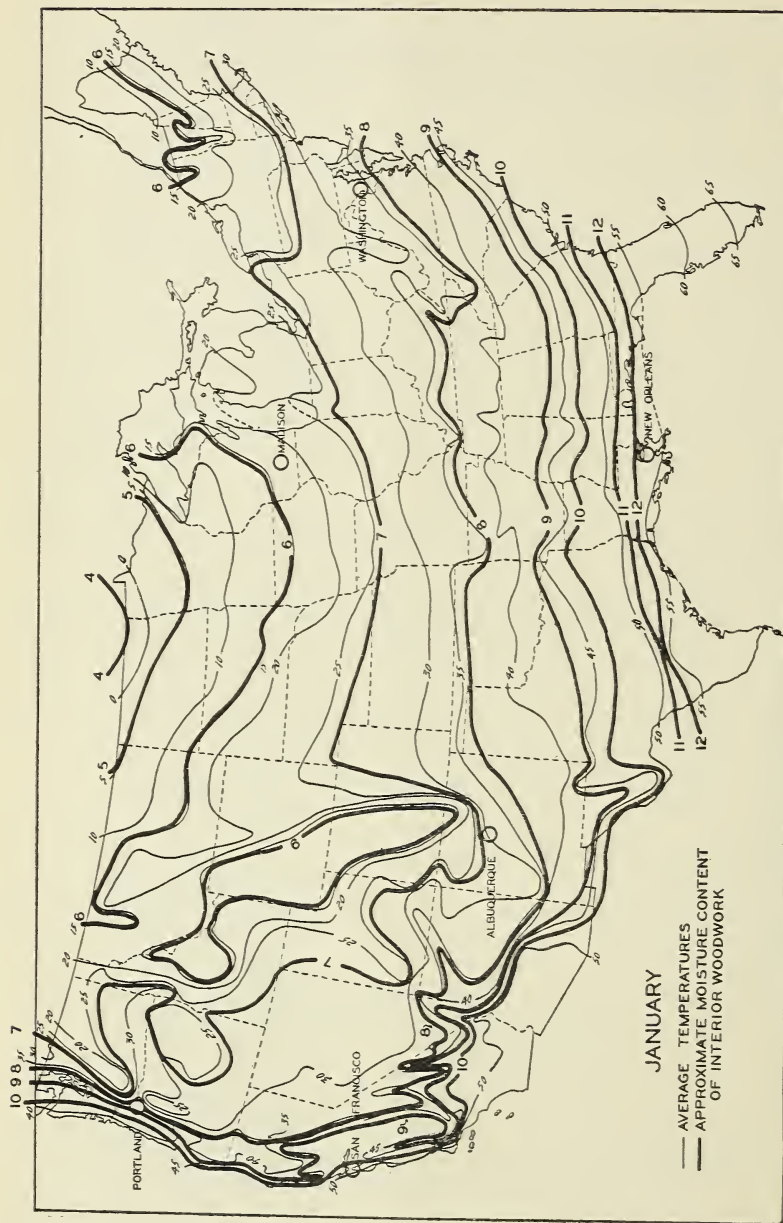


FIGURE 7.—Average outdoor temperatures and approximate moisture content of interior woodwork in heated dwellings in the United States during January

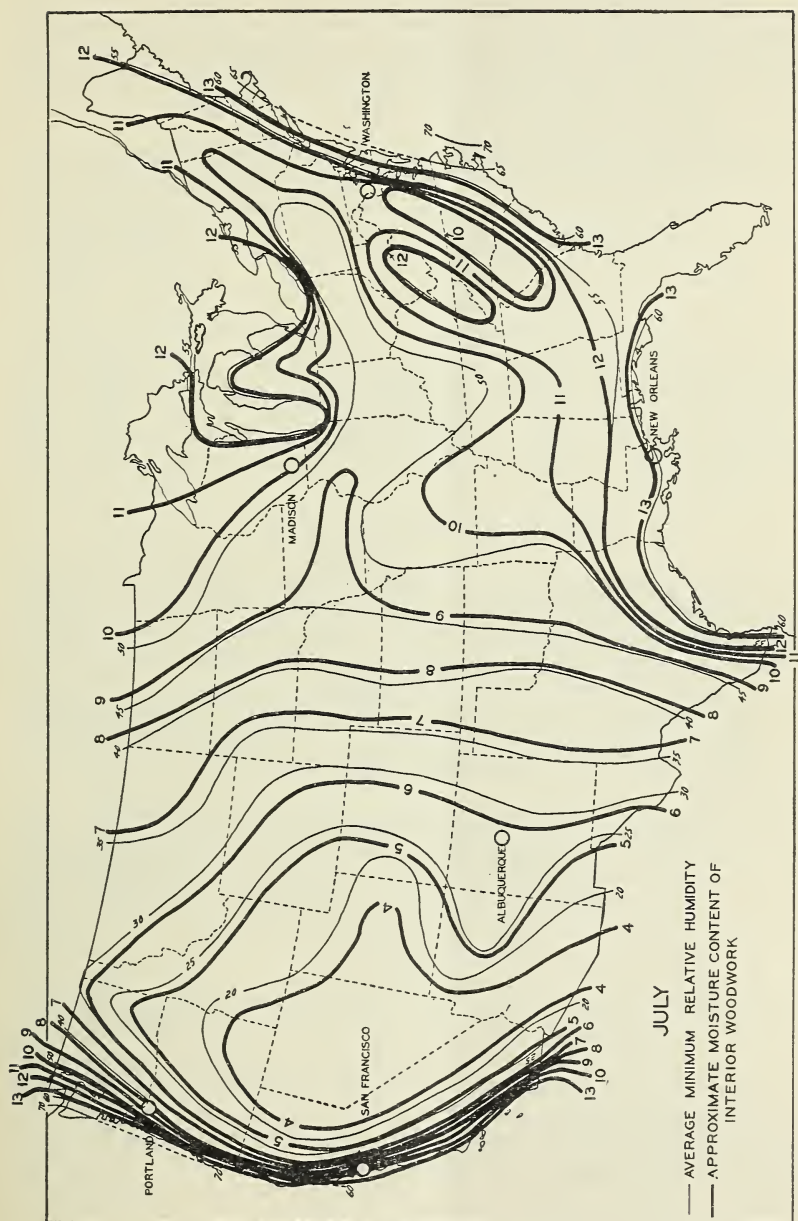


FIGURE 8.—Average minimum relative humidity and approximate moisture content of interior woodwork in the United States during July

Table 2, which is based on the preceding maps and confirmed by other studies, gives a general idea of the moisture-content values to be expected in interior woodwork in the various parts of the United States. These values are not in all instances the extremes, although they are more nearly so in those places that have a long and definite heating season. The longer a building is without heat the more the moisture content of the interior woodwork is affected by spasmodic periods of abnormal weather, such as damp or dry spells.

TABLE 2.—*Estimated average moisture content of the principal interior woodwork in 13 widely separated cities during January and July*

| City                     | Moisture content of interior woodwork |                 | City                      | Moisture content of interior woodwork |                 |
|--------------------------|---------------------------------------|-----------------|---------------------------|---------------------------------------|-----------------|
|                          | July                                  | January         |                           | July                                  | January         |
|                          | <i>Per cent</i>                       | <i>Per cent</i> |                           | <i>Per cent</i>                       | <i>Per cent</i> |
| Atlanta, Ga.....         | 11.5                                  | 8.5             | New York, N. Y.....       | 12.5                                  | 7.0             |
| Albuquerque, N. Mex..... | 6.0                                   | 7.0             | Portland, Oreg.....       | 9.5                                   | 9.0             |
| Boston, Mass.....        | 13.0                                  | 7.0             | Salt Lake City, Utah..... | 4.0                                   | 7.0             |
| Dallas, Tex.....         | 9.0                                   | 9.0             | San Francisco, Calif..... | 10.5                                  | 10.5            |
| Duluth, Minn.....        | 10.5                                  | 5.0             | Seattle, Wash.....        | 11.0                                  | 8.5             |
| Madison, Wis.....        | 10.0                                  | 6.0             | Washington, D. C.....     | 11.0                                  | 8.0             |
| New Orleans, La.....     | 13.5                                  | 12.5            |                           |                                       |                 |

#### MOISTURE SPECIFICATIONS

The information presented in Figures 3 to 8 shows the impossibility of building each piece of wood into the house with a final guaranty against any moisture change. Lumber that is produced at one place must be used in many places. Manufactured in one season, it must last the owner throughout all seasons. Ideal, perhaps, in its moisture content for use in the hallway, it has to be used in the bathroom and attic as well. How, then, can the architect or owner demand any particular degree of seasoning in any one lot of lumber?

It can be done, provided reasonable generalizations are made. (1) Conditions in the "living" portion of the house (living room, bedroom, bathroom, and kitchen) may be taken as a criterion of the moisture cycle for the most important woodwork in a house. (2) Local climatic conditions may be used as the standard for specifying the moisture content for the interior woodwork.

Fortunately, the climatic conditions for the United States are such that they may be divided into three general regions—the dry Southwest, comprising Nevada and parts of Oregon, Idaho, Utah, Arizona, and California; the damp southern coastal regions and the southern coast of California; and the remainder of the United States—and specifications for the moisture content for wood in dwelling houses based on the results shown in Figures 3 to 6 can be made applicable to each region. (Table 3 and Fig. 9.)

TABLE 3.—*Recommendations for initial moisture content of lumber for dwellings*<sup>1</sup>

| Use of lumber                                      | Moisture content (per cent of weight of oven-dry wood) for— |                         |                               |                         |                                |                         |
|----------------------------------------------------|-------------------------------------------------------------|-------------------------|-------------------------------|-------------------------|--------------------------------|-------------------------|
|                                                    | Dry South-western States                                    |                         | Damp South-ern coastal States |                         | Remainder of the United States |                         |
|                                                    | Aver-age                                                    | Toler-ance <sup>2</sup> | Aver-age                      | Toler-ance <sup>2</sup> | Aver-age                       | Toler-ance <sup>2</sup> |
| Interior finishing woodwork and flooring.....      | 6                                                           | 4-9                     | 11                            | 8-13                    | 8                              | 5-10                    |
| Sheathing, framing, siding, and exterior trim..... | 9                                                           | 7-12                    | 12                            | 9-14                    | 12                             | 9-14                    |

<sup>1</sup> The moisture-content values listed here are subject to revision as more complete information becomes available.

<sup>2</sup> Refers to individual pieces.

Owing to the small number of houses and regions studied, the moisture-content values given in the following specifications can not be considered final; it is believed, however, that in their present form they will afford the manufacturer, dealer, and consumer considerable protection from the troubles resulting from the use of wood improperly seasoned, even though they may be subject to re-

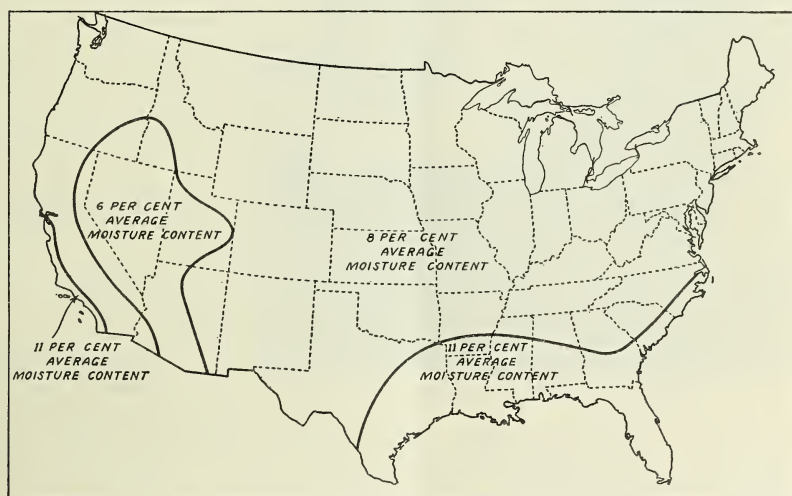


FIGURE 9.—Recommended moisture-content averages for interior-finishing woodwork for use in various parts of the United States

vision as more complete information becomes available. In the dry southwestern region of the United States the moisture content of any individual piece of interior-finishing woodwork at the time of installation should be between 4 and 9 per cent; sheathing, framing, siding, and exterior trim should have a moisture content of between 7 and 12 per cent. In the very moist southern coastal regions the moisture content of any individual piece of interior-finishing woodwork at the time of installation should be between 8 and 13 per cent; that of sheathing, framing, siding, and exterior trim should be

between 9 and 14 per cent. For the rest of the United States the moisture content of any individual piece of interior-finishing woodwork at the time of installation should be between 5 and 10 per cent; sheathing, framing, siding, and exterior trim should have a moisture content of between 9 and 14 per cent.

For any single specification of the moisture content of woodwork that is to be installed where the moisture conditions are definitely known, the moisture tolerances given in the foregoing specification can be reduced considerably.

It will not be necessary to specify the exact manner in which the inspector shall determine whether or not the woodwork meets the moisture specification. At present there are two recognized methods for making this determination. One is the oven-drying method and the other is the electrical method.

#### THE OVEN-DRYING METHOD OF DETERMINING THE MOISTURE CONTENT OF WOOD

The oven-drying method of determining the moisture content of wood that is more or less standard throughout the woodworking industries is as follows: A cross section three-fourths inch along the grain is cut approximately 2 feet from the end of the board. The section is weighed immediately on a sensitive scale and then placed in a drying oven and kept at a temperature of about 212° F. until it no longer loses weight, which is usually from 12 to 24 hours. The section is then removed from the oven and again weighed, the scale reading being the "oven-dry" weight of the wood—the weight of the actual wood substance. The difference between the original weight and the oven-dry weight is the weight of the water originally in the section.

In calculating the moisture percentage, first divide the difference between the original weight and the oven-dry weight by the latter, and then multiply by 100. The formula is as follows:

$$\text{Moisture content in per cent based on oven-dry weight} = \frac{\text{original weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100$$

Thus, if the original weight is 180 grams and the oven-dry weight is 150, a difference of 30 grams, the moisture percentage will be  $\frac{30 \text{ grams}}{150 \text{ grams}} \times 100 = 20$  per cent. The moisture content so determined is based on the oven-dry weight of the wood, a practice almost universal.

#### THE ELECTRICAL METHOD FOR DETERMINING THE MOISTURE CONTENT OF WOOD

The electrical method for determining the moisture content of wood is based upon the well-known fact that the electric resistance of wood changes with moisture content. There are several types of portable electrical moisture instruments now on the market. The features common to the present instruments are two sharp metallic terminals that can be quickly embedded in the wood, batteries for supplying an electric current through the wood intervening between the two terminals, and a means for reading the resistance in the

electric circuit directly in terms of the moisture content of the wood holding the terminals. (Fig. 10.) The range of the present instruments is about 8 to 24 per cent moisture content.

The electrical method has an advantage over the oven-drying method principally on account of its speed and convenience, the time required to determine the amount of moisture in any piece of wood being only a few seconds. The moisture determination is usually made on the back of the piece somewhere near the center. This procedure avoids marring the face when the metallic terminal points are inserted. The electrical method is the only known practical means by which the moisture content of finished woodwork in place can be determined without serious injury to the wood.

#### MOISTURE CONTENT OF DIFFERENT KINDS OF WOOD

The moisture content of the principal interior woodwork is not materially affected by the kind of wood out of which it is made. This fact is based upon thousands of measurements made at the Forest Products Laboratory. It is also confirmed by a comparison of blocks of different species installed near each other in the various houses studied, which show that with the apparent exception of redwood there is little difference between the moisture-content values of the maple blocks and those of the other species used. (Fig. 11.) The slight discrepancy in the moisture-content values for redwood may possibly result from the effect of the high proportion of extractives present in the heartwood of this species, and is of little consequence for the purpose under consideration. The presence of extractives in the wood may be actually beneficial from the standpoint of tending to reduce the amount of shrinking and swelling for a given moisture change. Therefore no distinction, as a rule, need be made as to species of wood when specifying the moisture content desired for interior woodwork.

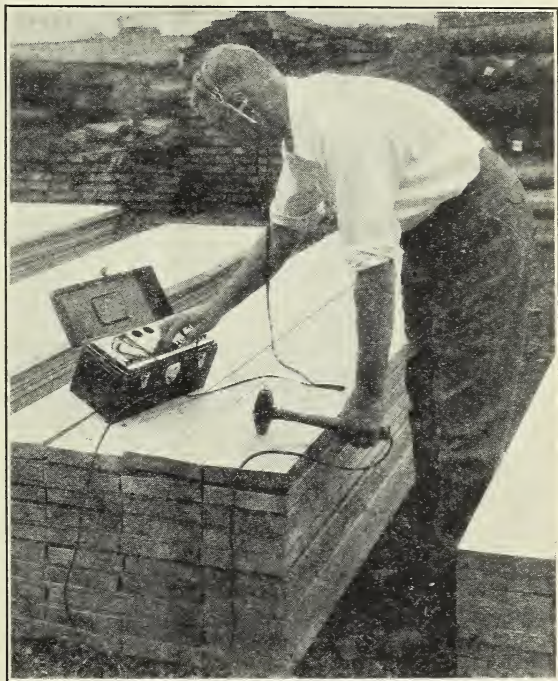


FIGURE 10.—An electrical moisture meter in use

#### EFFECT OF COATINGS ON THE MOISTURE CONTENT OF WOOD

No matter what kind of wood is used, how well it is selected, seasoned, machined, and put together, or how carefully it is finished

with filler, stains, varnish, and the like, the fact remains that wood takes on and gives off moisture with variations in atmospheric humidity and swells and shrinks accordingly. The rate of change may be much slower in wood that is well coated, but no coatings thus far

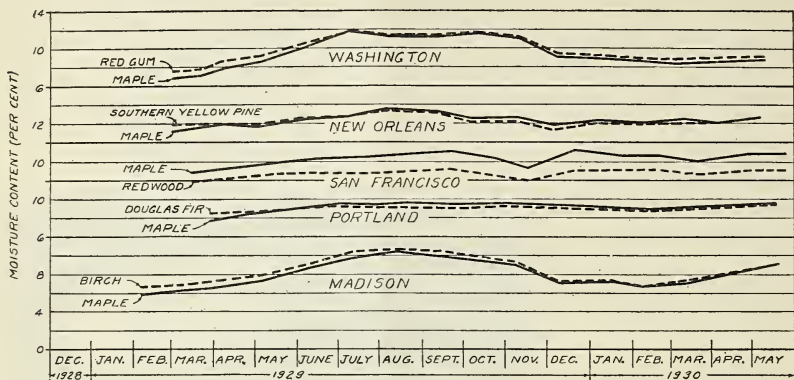


FIGURE 11.—The percentage moisture content of the principal interior woodwork of a house is not materially affected by the kind of wood out of which it is made. This graph is based on the average moisture content of shellacked blocks of different species in the "living" part of houses studied in six widely separated cities

discovered completely prevent moisture changes. Furthermore, woodwork in houses is seldom coated on all surfaces.

Figure 12 shows the moisture-content values of the maple blocks on the inner wall of the living room of a house at Madison, Wis.

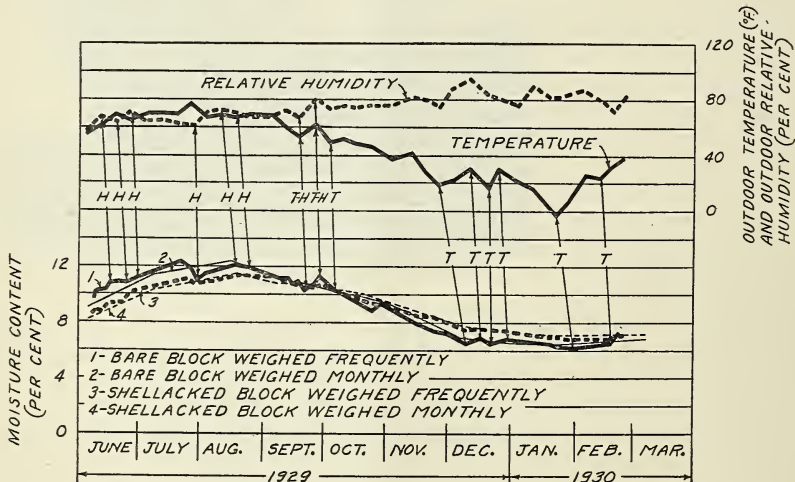


FIGURE 12.—Wood properly dried and then shellacked or similarly coated fluctuates less in moisture content under changing atmospheric conditions than uncoated wood. This graph is based on the average moisture content of maple blocks on the inner wall of the living room of a house at Madison, Wis., and on the corresponding weekly average outdoor temperature and relative humidity

These blocks were weighed much more frequently than was the regular custom. The difference in the rate of change in moisture content in the bare blocks and in the shellacked blocks when subjected to the same changes in temperature and relative humidity is brought

out clearly. The shellacked block lagged behind the bare block and did not pick up to so high a moisture-content peak in the summer and did not drop to so low a point in the winter as the bare block did. This, of course, resulted in a smaller seasonal variation in moisture content in the shellacked block than in the bare block. The points in curve No. 1 that could be correlated with the weekly average outdoor temperature and relative humidity changes are connected by lines. The many more fluctuations in curve No. 1 than in curve No. 3 show how much more quickly the moisture content of the bare blocks responded to weather changes than did the shellacked blocks.

Although shellac, varnish, enamel, paint, and similar coatings do not prevent the absorption and loss of moisture, their retarding effect prevents sudden changes in the moisture content of the woodwork, and this is of considerable practical importance.<sup>4</sup> As ordinarily used in houses, the main purpose of these coatings is decorative, but their protective effect is also of value, especially for the woodwork exposed to outdoor conditions. When the maximum effectiveness in retarding moisture changes is desired, coatings should be applied to all surfaces, not merely to the surfaces that are exposed to view.

#### RETAINING THE PROPER MOISTURE CONTENT IN LUMBER DURING STORAGE

In order to obtain wood that will meet a moisture-content specification for dwelling houses care must be taken to prevent increase in moisture content during its storage and handling. Ordinarily open storage sheds without side walls protect the wood only from the rain and not from the atmosphere, for wind can blow through them quite freely, and the average temperature and relative humidity within the shed will correspond closely with the shade conditions outside. (Fig. 13.) Closed sheds probably offer a little protection against quick atmospheric changes outside, but over a long period the average values of temperature are only slightly higher and the average values of relative humidity only slightly lower than in open sheds.

Consequently, when the distributor receives kiln-dried stock that has been properly dried to a low moisture content and desires to store it for a considerable period, it should be piled in heated sheds. (Fig. 14.) Whether the sheds are heated or not, bulk piling kiln-dried stock is desirable. (Fig. 15.) Thoroughly air-dried stock may also be bulk piled, but stock that is not thoroughly air dried should be placed in open piles with strips, or stickers, between the layers.

As in a dry kiln, the control of moisture content within the shed is a matter of temperature and relative humidity, and this is rather simple. Control of the relative humidity in storage sheds can be accomplished by controlling the temperature. It is necessary merely to keep the temperature a few degrees higher within the shed than outside, the exact amount depending on the outside humidity and the desired equilibrium moisture content.

<sup>4</sup> A comparison of the effectiveness of various coatings on wood is given in the following publication: HUNT, G. M. EFFECTIVENESS OF MOISTURE-EXCLUDING COATINGS ON WOOD. U. S. Dept. Agr. Circ. 128, 28 p., illus., 1930.

Figure 16 indicates what happens, in terms of the moisture content of wood, when air at a certain temperature and relative humidity is either heated or cooled. This figure is, therefore, especially useful in connection with the storage of wood inside sheds and other buildings. An example will explain the use of the chart. Assume that the atmosphere in a shed or other building is maintained at a relative humidity of 50 per cent and a temperature of

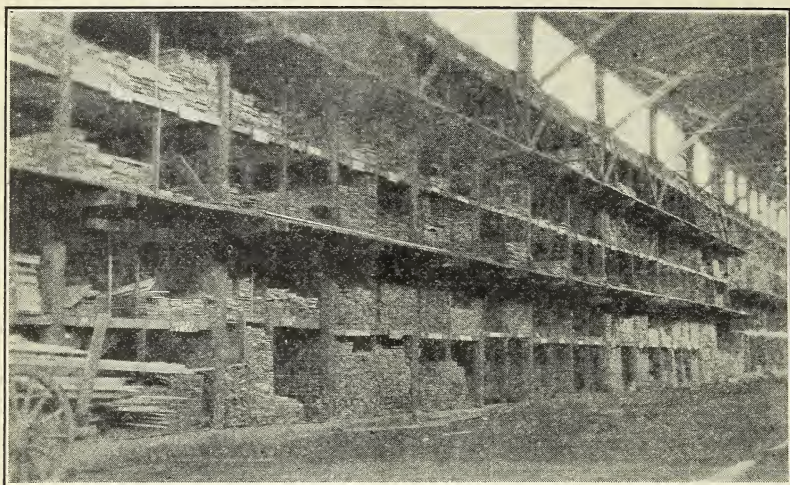


FIGURE 13.—A representative lumber storage shed of the class in which the stock is protected from the weather although not from the atmosphere

70° F. and it is desired to find the moisture content that will be eventually reached by the wood stored within. Start with the relative humidity. Follow the horizontal relative-humidity line from the scale at the left border of the chart, which in this example is 50 per cent, to its intersection with the vertical line from the scale at the lower border representing the temperature, which in this example is 70°. Then follow along or parallel to the slightly sloping straight line passing through this intersection point until it reaches the scale



FIGURE 14.—A good example of an inclosed storage shed for dry lumber

at the right border of the chart from which the equilibrium moisture content is read, which in this example is about 9 per cent. If, at this time, it is desired to further dry the wood within the shed, say to 7 per cent moisture content, proceed as follows: The curved lines running diagonally across the chart represent the vapor pressure in inches of mercury. Follow along or parallel to the vapor-pressure curve, passing through the intersection of the initial temperature

and relative humidity, which in this example is the curve marked 0.360, until it intersects the slightly sloping straight line representing the equilibrium moisture content given on the scale at the right border, which in this example is 7 per cent. Then follow along or parallel to the vertical line passing through this intersection to the scale at the bottom of the chart, from which the desired temperature is read, which in this case is about 78° F.

Again, if it is necessary to store, with no increase in moisture, high-grade lumber that has been kiln-dried down to, say, 10 per cent moisture content, Figure 16 shows what steps must be taken. Assuming that the lumber is to be stored in a locality that has an average winter temperature of 30° F. and a relative humidity of 80 per cent, a temperature of 40° must be maintained inside the storage shed. This means an average increase in temperature of only 10° above the outside temperature. If the average summer conditions were 70° and 70 per cent relative humidity, then an average temperature of 76° must be maintained. The foregoing values are obtained by following from the relative-humidity value on the scale at the left, horizontally across the chart to the intersection with the vertical through the temperature value, then following along parallel to the curved lines to the point where the slightly sloping straight line representing the desired equilibrium-moisture content is intersected; from this point the required temperature is read from the scale directly below.

If the moisture-content tests of the buyer are made close to the ends of boards, stock from unheated sheds that has been in storage for a considerable period will show a high average moisture content in comparison with stock stored for a similar period in heated sheds. Stock from heated storage should be practically uniform throughout the board length upon reaching equilibrium-moisture content, and with such stock it will make little difference where the tests are made on the boards.

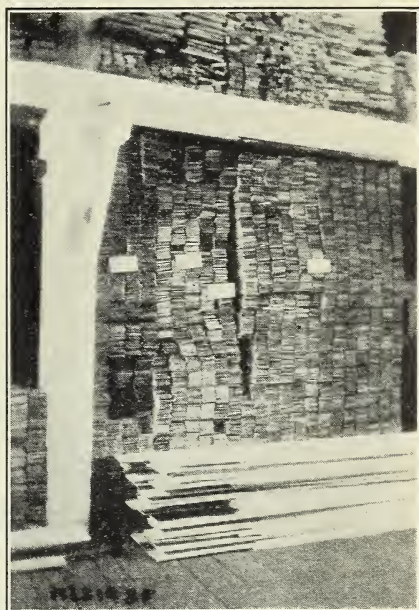


FIGURE 15.—The major portion of this lot of dry lumber is tightly bulk piled, and there should be little change in moisture within the pile. The ends, of course, will quickly change to the equilibrium moisture content of the atmosphere in the shed

#### MOISTURE ABSORBED AFTER DELIVERY

It sometimes happens that flooring is delivered to a building site and there piled on a rain-soaked subfloor or in the damp basement or otherwise left unprotected from rain or dampness for a considerable time, so that more or less moisture is absorbed by the exposed

boards in the bundles and in the ends of the stock. Laid in this condition, the flooring is bound to show gross irregularities in a short time. Very bad results may also be expected if the flooring is laid or even stored inside the house before the plaster or masonry of the walls has had time to become thoroughly dry, but even without this type of more or less obvious exposure of the wood to moisture, there is another type of exposure less obvious but no less important. During the time of laying the floor, scraping it, and completing the other items up to the time of occupancy, the general temperatures within the house during the winter are likely to be lower and the relative humidities higher than those that would occur in the same house if it were occupied.

Where a succession of damp days follow immediately after the floor is laid and before the finish can be placed upon it, a very important increase in moisture content is likely to occur. The increase, of course, is slower after a floor has received even the first coat of its final finish, as shown by Figure 12. Even a moderate

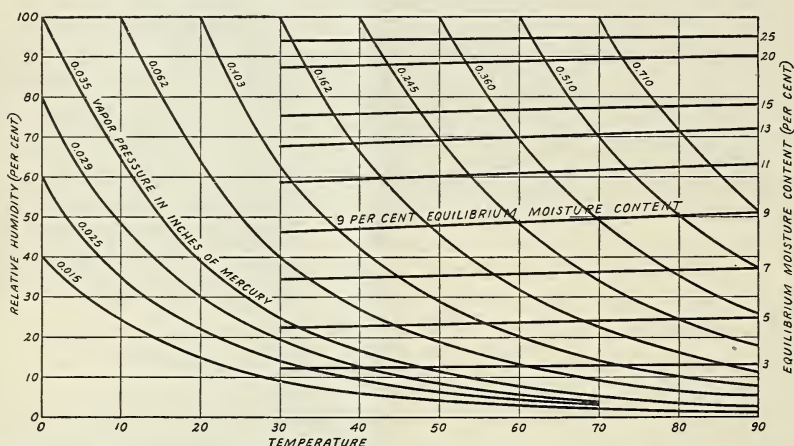


FIGURE 16.—Relationship among relative humidity, vapor pressure, equilibrium moisture content, and temperature

absorption of moisture from the air is sufficient to cause a perceptible bulging of certain boards where they resist one another in the natural tendency to swell. Some crushing of wood fiber is bound to result from moisture increase in a tightly laid floor, and this crushing, which is technically known as compression set (fig. 17), is the common cause of much of the cracking between boards in flooring. If one were able to examine some well-laid flooring and see just how the edges go together, he would find that there is a relatively narrow edge that has to take the first results of the compression, though the whole board takes up some of the compression. After a board has once been in this compressed condition it never again completely recovers.

A second moisture change in which a loss in moisture occurs takes place after the house is occupied, particularly during the winter when the house is heated; at this time the average humidity is lower than it was during the construction period. Each board simply backs away from its neighbor (fig. 17, C), and the crack may be

wider if the floor was laid too green. Any subsequent pressure contact between boards as a result of moisture changes increases the width of the cracks as the wood again dries out. Such pressure may occur during a period when the house is unoccupied or unheated for several weeks during cold or damp weather or from

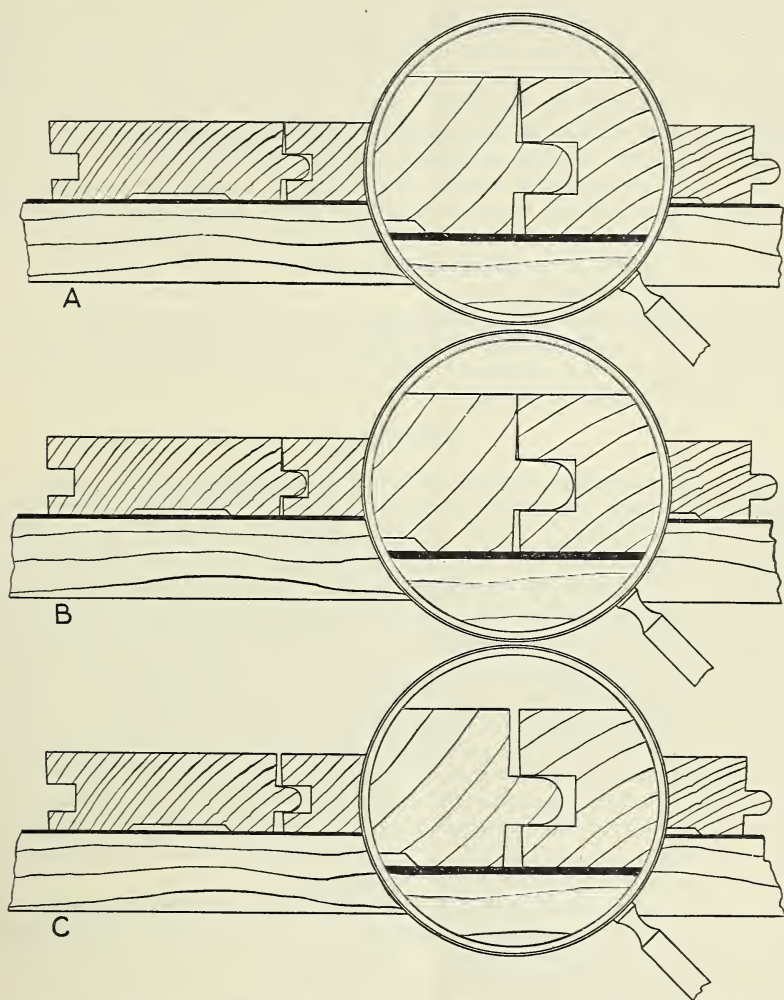


FIGURE 17.—How compression set and shrinkage make cracks: A, Flooring when laid; B, the same flooring after it has absorbed moisture as a result of damp conditions in the unfinished house; C, the same flooring after subsequent drying to a lower moisture content than when laid. Note the permanent deformation of the inverted V-shaped joint and the comparatively wide crack

contact with foreign matter in the cracks. Another example of this process is the typical kitchen floor, in which repeated scrubbing causes the cracks to grow wider and wider as the floor grows older.

Consequently any complete specification of the moisture content of the wood to be used in dwellings should give the buyer assurance that the stock will be properly protected during and immediately

after delivery. Flooring and other tight-fitting interior woodwork should not be delivered on a damp or rainy day, nor before the plaster or masonry walls are dry.

In addition, heat should be maintained in the house from the time the flooring and other interior woodwork are delivered until the house is occupied. The house interior should be kept at a temperature corresponding approximately to that of the proper moisture content of the interior woodwork (pp. 15 and 20). While temperatures a little higher than this will do no harm, any severe overheating should be avoided. After the flooring has received the protective coat of finish, temperatures comparable with those occurring in the house during occupancy should be maintained. No heat, of course, is required in warm, dry weather, but spells of damp or cool weather are likely to occur in any month of the year. Whenever possible the heating plant should be placed in the house before the interior trim goes in, in which event it will be available as a means of supplying the necessary heat.

An additional and very important reason for keeping down moisture in the house nearing completion is the fact that better and smoother floors are obtained with mechanical sanders when the floor and atmosphere are dry.

#### SUMMARY

What the moisture content of wood in dwelling houses should be depends on what the wood is to be used for and where it is to be used. A preliminary study of the moisture content in dwelling houses indicates that for any individual piece of interior-finishing woodwork to be used in dwellings in most parts of the United States the moisture content at the time of installation should be between 5 and 10 per cent of the weight of the oven-dry wood; in the damp southern coastal regions, where the humidity is high, the moisture content should be between 8 and 13 per cent; and for the dry southwestern region, where the humidity is low, the moisture content should be between 4 and 9 per cent. For sheathing, framing, siding, and exterior trim to be used in dwellings in most parts of the United States the moisture content of any individual piece at the time of installation should be between 9 and 14 per cent of the weight of the oven-dry wood, and in the dry southwestern regions the moisture content should be between 7 and 12 per cent.

In so far as is practicable wood should be protected against extreme changes in atmospheric humidity or direct contact with water during and after manufacture. This may be done in the storage shed by installing suitable heating equipment.

The builder or owner of a new house should assure himself that the dealer has properly protected the stock from the weather while it was in his hands. Flooring and other interior woodwork should not be delivered on a damp or rainy day, nor before the plaster or masonry walls are dry. It is well to maintain some heat in the house from the time the interior-finishing woodwork is delivered until the house is occupied.



